DOCUMENT RESUME

ED 187 734 TM 800 229

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TITLE The Relationship between Visual Thinking Tasks and Problem-Solving Performance.
INSTITUTION Bowling Green State Univ., Ohio.
PUB DATE Apr 80
NOTE 25p.; Paper presented at the Annual Meeting of the American Educational Research Association (64th, Boston, MA, April 7-11, 1980)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Abstract Reasoning; *Age Differences; Cognitive Tests; Creativity; Elementary Secondary Education; Grade 5; Grade 9; Higher Education; *Mathematics; Perception Tests; *Problem Solving; *Sex Differences; *Spatial Perception; Undergraduate Students; *Visualization
IDENTIFIERS *Problem Solving Test (Moses)

ABSTRACT

This investigation analyzed sex-related and age-related differences on spatial visualization tasks, reasoning tasks, and mathematical problem-solving tasks; and the effects instruction in visual thinking would have on these differences. Students in fifth grade, ninth grade, and in college, were tested before and after twelve weeks of instruction on seeing, imagining, and drawing two-and three-dimensional figures. Four tests were used to measure spatial visualization: the Mental Rotations Tests, and three sections of the Kit of Reference Tests for Cognitive Factors: Punched Holes Test, Form Board Test, and Hidden Figures Test. There were two measures of reasoning: Nonsense Syllogisms Test, and Reasoning Test; and a newly-developed problem-solving test. Results indicated that problem-solving correlated significantly with spatial skills, reasoning skills, and degree of visuality. Older students performed significantly better on all tests. Males performed better on spatial tasks while females performed better on reasoning tasks; with increasing age, the gap between sexes widened on spatial and reasoning tasks, but not on problem-solving tasks. Instruction affected spatial and reasoning ability, but not problem-solving performance or degree of visuality. (The problem solving test is appended). (CP)

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THE RELATIONSHIP BETWEEN VISUAL THINKING TASKS AND PROBLEM-SOLVING PERFORMANCE

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Paper presented at the annual meeting of AERA, Boston, April 1980.

TM800 229

Department of Mathematics & Statistics, Bowling Green State University, Technical Report No. 80-08, April, 1980.

ABSTRACT

This investigation attempted to analyze sex-related differences and age-related differences on spatial visualization talks, reasoning tasks and mathematical problem-solving tasks, and the effects that a well-developed sequence of visual thinking exercises would have on these differences. Using two classes each of fifth-grade, ninth-grade and university-level students, a comparison of the groups was made before and after instruction, where only half of the population at each grade level received the special instruction. It was found that males are better at spatial tasks and females are better at reasoning tasks (particularly at the university level) but that instruction can close the gap.

THE RELATIONSHIP BETWEEN VISUAL THINKING TASKS AND PROBLEM-SOLVING PERFORMANCE

Many researchers in mathematics education have sought to analyze the nature of creative mathematical talent. Certain studies have been clinical in nature, where the investigator has interviewed mathematically-gifted students and has attempted to determine whether there was some underlying cognitive style and/or general ability that these gifted students possessed (Krutetskii, 1969). Other studies have factor-analyzed a large battery of tests containing measures of general cognitive abilities, as well as specific mathematical abilities, using large random sample populations; these studies have sought to determine whether certain groups of tests are distinguishable from one another, whether each of these groups have a known cognitive factor in common and whether any of these groups correlate significantly with problem-solving performance (Werdelin, 1958). For example, a certain group of tests may load heavily on one factor, and it may be noted that these tests all measure logical reasoning ability. In addition, another set of tests may load heavily on a second factor, and these tests may all be measuring numerical ability. Both of these groups of tests may correlate strongly with problem-solving performance.

Truly creative problem-solving performance appears to involve more than facility with computation. Knowing certain techniques or algorithms (e.g., how to divide, how to differentiate) is not sufficient. Researchers using clinical methods and researchers using factor analytic

methods have observed that successful problem solving involves an "aha" experience which consists of a successful combination of insight and proper background information. Although the mathematical experiences of two students may be similar, it is often the case that one of them will solve a problem while the other does not know how to begin. Moreover, it is not true that with additional mathematical experiences students will automatically become better problem solvers. As Abraham Maslow claims, conscious primary creativity is "lost by most people as they grow up." This may, in fact, be due to the sterile, analytic classrooms that foster rule-finding and algorithmic thinking. After years in the traditional classroom, the typical student attempts to solve problems by fitting them to known molds rather than perceiving the problem situation in a broad context.

With current trends in mathematics education leaning towards "back to basics," educators need to question the appropriateness of this movement. If indeed the "back to basics" movement means a return to drill worksheets, additional practice in memorizing the basic facts, and rote learning of different algorithms, then it may well be the case that this movement of the '80's is hampering creative problem solving. What we need to understand at this point is what skills affect the problem-solving process and how and when these skills are developed.

Purpose of the study.

This investigation attempted to analyze some skills which may play a role in the problem-solving process and to determine differences in

these skills and in problem solving itself due to age and sex. The study then attempted to analyze the effects that a well-developed sequence of visual thinking tasks might have on all of these variables. In particular, the following major questions were considered:

(1) Is there a relationship among problem-solving skills, reasoning skills and spatial visualization skills?

(2) What effect, if any, does age have on performance on problem-solving tasks, on spatial visualization tasks and on reasoning tasks?

(3) What effect, if any, does sex have on performance on problem-solving tasks, on spatial visualization tasks and on reasoning tasks?

(4) Do differences among males and females on performance on problem-solving tasks, on spatial visualization tasks and on reasoning tasks change with age?

(5) Will instruction in visual thinking tasks affect problem-solving performance? Will it affect visualization skills and/or reasoning skills? Will these effects be different for males than females? Will these effects be different for older students than for younger students?

Selection and description of the sample population.

In order to study differences that occur due to age and experience, three distinct grade levels were selected--one at the elementary school level, one at the secondary school level, and one at the university level. Two fifth-grade teachers at Conneaut Elementary School in Bowling Green expressed their willingness to aid in the study. One

ninth-grade teacher at Bowling Green Junior High School and one university professor at Bowling Green State University also participated.

Each of the two fifth-grade teachers was responsible for one classroom, giving a total of two fifth-grade classrooms, or approximately 60 students. The ninth-grade teacher was responsible for four classes, again comprising approximately 60 students. Finally the university professor was responsible for two classrooms, or approximately 50 students. (This last group consisted of students enrolled in a mathematics course for pre-service elementary teachers.) A total of 170 students from eight classes were involved in the study.

Most of the students were from middle-class families. Many of the students at the elementary school and at the junior high school were children of university faculty.

At each grade level, one of the classes was randomly selected to serve as an experimental class, and the remaining classes were designated as control classes. Since intact classrooms were used (and not random assignment of students to experimental or control classes), the measure of statistical analysis was the classroom ($N = 8$) in certain statistical analyses.

The three grade levels were selected based on the possible heterogeneity of cognitive stages in which the students might be. Although some consideration was given to selecting a lower grade at the elementary level, this idea was rejected due to: (a) the lack of mathematical skills that such students would possess; (b) the inability of such students to perform well on certain measures of reasoning skills and spatial visualization skills.

Procedure.

The study was carried out over the 1979-80 academic year. There were three phases to the investigation--the administration of the pretest battery, the instructional phase, and the administration of the posttest battery.

During the first two weeks of the study, all pretest evaluation instruments were administered to both the experimental and the control classes. During the following 12 weeks, the investigator administered the sequence of lessons concerned with visual thinking tasks to the experimental classes; the control classes received the normal mathematics instruction by the regular teacher. During the final week of the investigation, the same evaluation instruments were administered to both the experimental and the control classes.

The same set of seven tests made up both the pretest and posttest battery. These tests included four spatial visualization tasks, two reasoning tasks and a problem-solving test. The four spatial tests selected were: Mental Rotations Test, Punched Holes Test, Form Board Test, and Hidden Figures Test. The two reasoning tests were the Nonsense Syllogisms Test and Reasoning Test. The problem-solving test was a selection of ten non-algorithmic tasks compiled by the investigator.

A brief description of each test, accompanied by a sample item, follows:

1. Mental Rotations Test

This test was constructed by Stafford. The purpose of the test is to measure the ability to perceive mentally the relationships among

the elements of a figure in order to identify the figure when its orientation has been changed. In each item there is a given three-dimensional configuration. This is followed by five other three-dimensional figures, only one of which is a rotation of the original figure. The individual must circle the configuration which is a rotation of the original configuration. A sample item is given in Figure 1.

Figure 1. Item from Mental Rotations Test

2. Punched Holes Test

This test is part of the *Kit of Reference Tests for Cognitive Factors*. The modified form used here is from the NLSMA battery. The purpose of the test is to measure the ability to manipulate mentally given spatial patterns into other visual configurations. In each item, a square sheet of paper is shown folded two or three times, and a hole is then punched through all of the thicknesses. Each of the folding moves as well as the punching move is illustrated in a separate picture. The individual must then select which one of five squares with holes in them would be the actual representation of the original paper when unfolded. A sample item is shown in Figure 2.

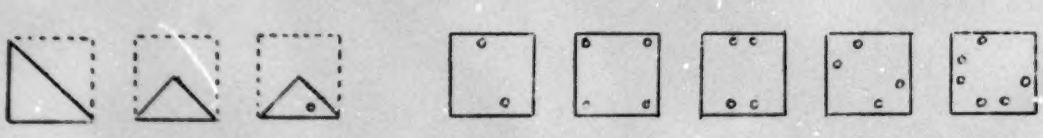

Figure 2. Item from Punched Holes Test

3. Form Board Test

This test is part of the *Kit of Reference Tests for Cognitive Factors*. The modified form used here is part of the NLSMA battery. The purpose of the test is to measure the ability to manipulate mentally one spatial pattern into other visual configurations. In each item, there is a picture of a square with part of the square missing. The task is to determine which two of five pieces shown could be used to complete the square. A sample item is shown in Figure 3.

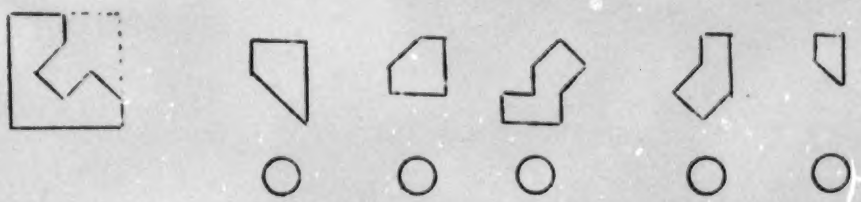

Figure 3. Item from Form Board Test

4. Hidden Figures Test

This test is part of the *Kit of Reference Tests for Cognitive Factors*. The purpose of the test is to measure "the ability to hold a given visual percept or configuration in mind so as to disembed it from other well-defined perceptual material" (Ekstrom, 1976, p. 19). At the top of each page, there are five geometric figures. In each test item, the individual must decide which of the five figures is contained in a complex pattern. Some sample items are shown in Figure 4.

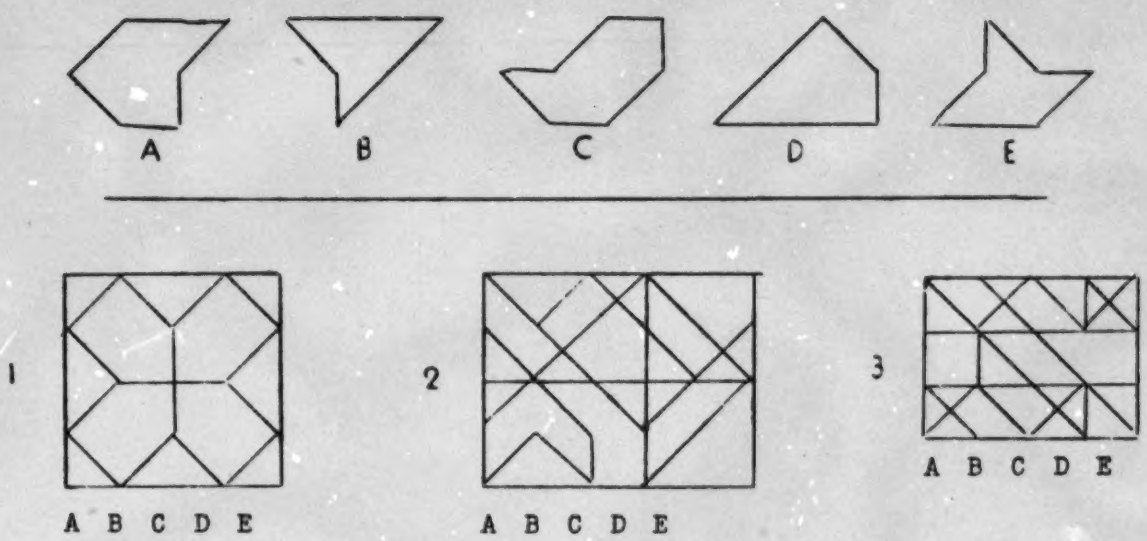

Figure 4. Items from Hidden Figures Test

5. Nonsense Syllogisms Test

This test is part of the *Kit of Reference Tests for Cognitive Factors*. The purpose of the test is to measure the ability to reason from givens to a conclusion. In each item there are two statements with nonsensical content followed by a conclusion, also of nonsensical content. The individual must determine whether the conclusion logically follows from the original two statements. Since all the statements are nonsensical, no conclusions can be drawn from past knowledge. A sample item is shown in Figure 5.

All elephants are pink. This animal is pink. Therefore this animal is an elephant.

Figure 5. Item from Nonsense Syllogisms Test

6. Reasoning Test

This test was written by Werdelin. The purpose of the test is to measure inductive reasoning, as in the Nonsense Syllogisms Test, except that the content is not nonsensical. In each item, there is some information given and then a question is asked. The individual must decide whether the answer to the question is yes, no, or not answerable, based on the given information. A sample item is shown in Figure 6.

Phil is weaker than Owen and Phil is stronger than Terry. Is Owen stronger than Terry?
A. Yes B. No C. Can't tell

Figure 6. Item from Reasoning Test

7. Problem-Solving Test

This test was constructed by the investigator (see Appendix A). The purpose of the test is to measure problem-solving performance and types of solution processes. The test consists of ten non-routine mathematics problems. The individual was instructed to show "everything that comes into your mind" as he/she was attempting to solve the problems. Two separate scores were obtained from the Problem-Solving Test. The first score, a problem-solving performance score, indicated the number of correct responses to the ten problems on the test. The second score, a degree of visuality score, indicated the extent to which the individual used visual solution processes (e.g., drawings, graphs, tables) in solving the ten problems. For each problem, a score of 0, 1, or 2 was assigned; the degree of visuality score was the sum of these scores.

All of the instruction was presented by the investigator in order to minimize differences between classes that might result from varied teaching techniques. The instruction focused on the three major facets of visual thinking -seeing, imagining and drawing. All three facets were active experiences.

The instructional phase began with an in-depth study of the cube. The students compared cubes with other three dimensional shapes (e.g., pyramids, cylinders, cones, rectangular/hexagonal/octagonal prisms and spheres), sorting out relevant from irrelevant characteristics of the various shapes. Imagining tasks and drawing tasks (including perspective experience) were tackled. Then the cube was "taken apart" and the different arrangements of six squares were studied in an attempt to decide which ones would form cubes. Rotations of some of these arrangements were considered. The cube was then reconstructed using some of these arrangements on construction paper or via D-stix or clay. Having had all of these experiences with the cube, the students then worked with a SOMA Cube, constructing different prescribed configurations.

The second portion of the instructional period concentrated on two-dimensional configurations. The students used the geoboards to construct specified shapes and discovered the method of enlarging an n-sided polygon to an (n+1)-sided polygon. Many frequently-used area formulas were derived. Areas of complex polygons were analyzed. Visual skills (e.g., noticing symmetries, seeing simple figures contained within complex polygons) were emphasized. Having had all of these experiences with two-dimensional shapes, the students then

worked with tangrams, constructing prescribed configurations with given numbers of pieces.

The instruction was a totally hands-on experience. Drawing was encouraged throughout. (As might have been predicted, this worked more smoothly for the fifth-grade class.) All of the activities focused on the visual mode of thought rather than analytic methods.

Results

The means and standard deviations of the raw scores on the seven tests are summarized in Table 1.

TABLE 1. DESCRIPTIVE STATISTICS

Test	Maximum Possible Score	Mean	Change from pretest to posttest	Standard Deviation
Mental Rotations Test (MR)	24	6.42	(+ .2)	4.36
Punched Holes Test (PH)	10	5.07	(+ .7)	2.36
Form Board Test (FB)	24	9.19	(+1.3)	3.59
Hidden Figure Test*	9	3.25		2.44
Nonsense Syllogisms Test*	15	8.06		1.72
Reasoning Test (R)	20	11.75	(+1.5)	4.59
Problem-Solving Test:				
Problem-solving performance (PSP)	10	2.29	(+ .8)	1.66
Degree of visuality (DV)	20	6.51	(+1.8)	4.46

*These tests were discarded from all future analyses since both the fifth-grade classes and ninth-grade classes did not comprehend the directions.

Due to the large number of students involved, most of the correlations proved to be significant (see Table 2). However, certain stronger correlations should be noted. In particular, degree of visuality correlates significantly with the Punched Holes Test, while problem-solving performance correlates with the Reasoning Test, Mental Rotations Test, Form Board Test and Punched Holes Test. Most importantly, there is a significant correlation between problem-solving performance and degree of visuality.

TABLE 2. CORRELATION COEFFICIENTS

	MR	PH	FB	R	PSP	DV
PH	.32	1.00	.50	.40	.49	.37
FB	.43	.50	1.00	.42	.39	.30
R	.37	.40	.42	1.00	.48	.30
PSP	.36	.49	.39	.48	1.00	.45
DV	.14	.37	.30	.30	.45	1.00

NOTE: All of the correlations except DV-MR were significant for $p < .0001$.

The means were then compared on the seven tests at each grade level and also by sex at each grade level. These results are presented in Tables 3 and 4.

TABLE 3. MEANS AT EACH GRADE LEVEL

Test \ Grade	5th	9th	University
Mental Rotations	5.25	5.91	9.72
Punched Holes	3.43	5.95	6.00
Form Board	7.55	9.59	11.02
Reasoning	9.31	12.36	15.16
Problem-solving performance	1.22	2.25	3.33
Degree of visuality	4.45	7.11	6.35

NOTE: Based on pretest data only.

TABLE 4. MEANS BY SEX AT EACH GRADE LEVEL

Test \ Grade	5th		9th		University	
	Male	Female	Male	Female	Male	Female
Mental Rotations	5.64	4.97	6.18	5.44	13.33	9.45
Punched Holes	3.91	3.07	6.00	5.88	9.67	5.73
Form Board	7.73	7.41	10.00	8.88	17.67	10.53
Reasoning	9.64	9.07	12.00	13.00	11.67	15.43
Problem-solving performance	1.41	1.07	2.29	2.19	2.33	3.40
Degree of visuality	2.55	5.90	6.68	7.88	6.33	6.35

NOTE: Based on pretest data only.

It should be noted that there was an increase in mean scores on each test from fifth grade to ninth grade to university level. Moreover,

on each spatial test at every grade level it can be seen that males perform better than females. Females perform better than males on reasoning tasks. Females have higher degree of visuality scores (i.e., use more processes such as drawing pictures), but males appear to catch up by college.

A multivariate analysis of variance was performed to test for overall grade effect. The F-value was computed to be 2.38, significant for $p < .006$. Then separate analyses of variance were performed with each test as the dependent variable. In every case, grade was a significant independent variable for $p < .001$. A multivariate analysis of variance testing for overall sex effect showed sex was significant for $p < .006$.

In order to compare control and experimental classes, a separate analysis of variance was run on each of the six test scores. No significant differences were found between the two groups (based on pretest data only). Also a multivariate analysis of variance was performed. The F-value was found to be .87, so that $p = .52$. There was no overall difference between control and experimental groups.

Since no initial differences were found between the groups, a repeated measures design (using pretest and posttest scores) was used to compare gain scores between control and experimental classes on each of the six variables. These results are presented in Tables 5-10. (The university classes were omitted from these results due to the difference in the instructional phase.)

TABLE 5
INSTRUCTIONAL EFFECTS ON MENTAL ROTATIONS TEST

Source of variation	SS	df	F
Test (pretest vs. posttest)	11.14	1	1.98
Group membership×Test (control vs. experimental)	19.63	1	3.50*
Group×Grade×Test	2.52	1	.45
Group×Sex×Test	21.25	1	3.79**
Group×Grade×Sex×Test	.01	1	.00

*p < .07
**p < .06

TABLE 6
INSTRUCTIONAL EFFECTS ON PUNCHED HOLES TEST

Source of variation	SS	df	F
Test	31.23	1	14.22***
Group membership×Test (control vs. experimental)	.22	1	.10
Group×Grade×Test	1.38	1	.63
Group×Sex×Test	2.13	1	.97
Group×Grade×Sex×Test	.10	1	.05

***p < .001

TABLE 7
INSTRUCTIONAL EFFECTS ON FORM BOARD TEST

Source of variation	SS	df	F
Test	71.57	1	15.41***
Group membership×Test (control vs. experiment)	.55	1	.12
Group×Grade×Test	19.73	1	4.25**
Group×Sex×Test	17.07	1	3.68*
Group×Grade×Sex×Test	1.57	1	.34

*p < .06
**p < .05
***p < .001

TABLE 8
INSTRUCTIONAL EFFECTS ON REASONING TEST

Source of variation	SS	df	F
Test	116.81	1	19.60***
Group membership×Test (control vs. experimental)	104.28	1	17.50***
Group×Grade×Test	6.07	1	1.02
Group×Sex×Test	7.38	1	1.24
Group×Grade×Sex×Test	33.15	1	5.56**

**p < .02
***p < .001

TABLE 9
INSTRUCTIONAL EFFECTS ON PROBLEM-SOLVING PERFORMANCE

Source of variation	SS	df	F
Test	22.56	1	26.06***
Group membership×Test (control vs. experimental)	1.57	1	1.81
Group×Grade×Test	8.66	1	10.00**
Group×Sex×Test	.10	1	.12
Group×Grade×Sex×Test	.34	1	.40

**p < .01
***p < .001

TABLE 10
INSTRUCTIONAL EFFECTS ON DEGREE OF VISUALITY

Source of variation	SS	df	F
Test	128.44	1	19.85***
Group membership×Test (control vs. experimental)	9.55	1	1.48
Group×Grade×Test	5.01	1	.77
Group×Sex×Test	.80	1	.12
Group×Grade×Sex×Test	.08	1	.01

***p < .001

There were instructional effects on the Mental Rotations Test and the Reasoning Test.

Conclusions.

Several important differences were noted between certain groups on several of the variables proposed.

1. Problem-solving performance appears to correlate significantly with both spatial skills and reasoning skills. Moreover, problem-solving performance correlates with degree of visuality, i.e., individuals who were successful at problem solving tended to use visual solution processes. This relationship would probably be even stronger if the students would write down *all* of the solution processes they were using; many students feel inhibited about drawing pictures and this inhibition gets stronger as the students get older. It should be noted that the mean degree of visuality score was lower for university students than for ninth-grade students. The investigator hypothesizes that this decrease would be even more dramatic if the college students tested would have been science/mathematics majors rather than pre-service elementary teachers.

2. Age does play a significant role on problem-solving tasks, on spatial visualization tasks, and on reasoning tasks. The older students performed significantly better on all tests (the only exception to this conclusion is the result mentioned in the above paragraph concerning the degree of visuality score). A quick glance at the mean scores (Table 3) testifies to this fact, as do the analyses of variance.

3. Sex does play a significant role on spatial visualization tasks and on reasoning tasks. Males performed better than females on spatial tasks, and females performed better than males on reasoning tasks.

4. More striking than the sex-related differences *across* grade levels were the sex-related differences at each grade level. The gap between males and females gets noticeably wider from fifth-grade to ninth-grade to university on spatial visualization tasks. What appears to be a non-significant difference in spatial ability at fifth grade becomes very significant at college. Also the gap in reasoning ability between the sexes (in favor of females) gets bigger with older students. The results for problem solving are not as conclusive. Males score better at fifth-grade level and ninth-grade level, but females score better at college level. This may be due to the atypical sample population of pre-service elementary teachers.

These findings appear to confirm the idea that the stereotyped roles of males and females become stronger in the teen years. These roles include spatial experiences for males and analytic (e.g., reading) experiences for females.

5. The instruction in visual thinking tasks affected spatial ability and reasoning ability but did not affect problem-solving performance or degree of visuality. (There were, however, significant increases in problem-solving performance from pretest to posttest as noted in Table 9; these increases were about the same for the experimental and the control classes.) The instructional effects were greater for the older students in two scores--Form Board and problem-solving performance. The instructional effects were greater for females also on two tests--Mental Rotations and Form Board.

This finding indicates that spatial ability is not innate and can be improved. This improvement is most noticeable with female

students who have had very few spatial experiences and can profit considerably from exposure to such experiences (as were provided during the instructional phase of the study).

Significance of the study.

Creative visual thinking, as experienced by seeing, imagining and drawing activities, is sorely missing in the typical classroom schedule. There *are* sex-related and age-related differences on spatial tasks, reasoning tasks and problem-solving tasks, but some of these differences can be overcome by providing the proper sequence of visual thinking tasks in the classroom.

The notion that the typical female cannot perform as well as the typical male appears to be incorrect. Given the opportunity to develop certain spatial skills, females can succeed. Educators need to consider the development of these spatial skills. Moreover, it is hypothesized that the development of problem-solving skills could possibly be accomplished by a longer instructional period.

APPENDIX A
PROBLEM-SOLVING TEST

1. Suppose that there are five boys in a race. Tom came in first. John came in last. If Sam was ahead of Norm and Frank was just behind him, who came in second?

2. Imagine a jar with a lid that is 6 cm across. The jar is 8 cm high. At the bottom of the jar, there is a caterpillar. Each day the caterpillar crawls up 4 cm. Each night he falls down 2 cm. How long will it take him to touch the lid of the jar?

3. If there are 4 people in a room and everybody shakes hands once with each of the other people, how many handshakes will there be?

4. Suppose you are now 11 years old and your mother is now 30 years old. In how many years will your mother be <u>exactly</u> twice as old as you?

5. A farmer has pigs and chickens on his farm. There are 20 animals in all. If you count 56 feet in all, how many pigs and how many chickens does the farmer have?

6. A fireman stood on the middle step of a ladder, directing water into a burning building. As the smoke got less, he climbed up three steps and continued his work. The fire got worse so he had to go down 5 steps. Later, he climbed up the last six steps and was at the top of the ladder. How many steps were there?

7. In driving from town A to town D, you pass first through town B and then town C. It is ten times further from A to B than from B to C. It is ten times further from B to C than from C to D. If it is 1332 km from A to D, how far is it from A to B?

8. A special rubber ball is dropped from the top of a wall which is 16 m high. Each time the ball bounces half as high as the distance it fell. The ball is caught when it bounces one meter high. How many times did the ball bounce?

9. Susan has 5 pockets and 10 dimes. She wants to put her dimes into her pockets so that each pocket contains a different number of dimes. Can she do this? Explain.

10. There are three coins labeled A, B and C. One is a penny, one is a nickel, and one is a dime. Only <u>one</u> of the following sentences is true:

A is a penny
B is not a dime
C is not a penny

Then A is a _____, B is a _____,

and C is a _____.